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COMMONWEALTH OF AUSTRALIA
THE PATENTS ACT 1952

APPLICATION FOR A STANDARD PATENT

We, Commonwealth Scientific and Industrial Research Organisation

of Limestone Avenue, Campbell, ACT

hereby apply for the grant of a Patent for an invention entitled:

"Heat Pipe"

which is described in the accompanying Provisional Specification.

Our address for service is: c/- SIROTECH LIMITED
Intellectual Property Group
580 Church Street
RICHMOND Vic 3121

Dated this April 30, 1990

Commonwealth Scientific and Industrial Research
Organisation

By: Gary Nock
Registered Patent Attorney

To: THE COMMISSIONER OF PATENTS

AUSTRALIA
PATENTS ACT 1990

NOTICE OF ENTITLEMENT

I, KEN HAMILTON, of Sirotech Limited, 580 Church Street, Richmond, Victoria, on behalf of the applicant in respect of Application No. 75381/91, entitled:

"HEAT PIPE"

state as follows:

The person nominated for the grant of the patent has entitlement from the actual inventors,

Harry SALT, of 10 Oulton Street, North Caulfield, Vic. 3161
Donald James CLOSE, of C/- James Cook University, Townsville, Qld. 4810
Malcolm Kay PECK, of 8 Henry Street, Sandringham, Vic. 3191
Ronald George HISKINS of 6 Carawatha Drive, Doncaster, Vic. 3108

by virtue of the fact that, at the time the invention was made, the actual inventors were officers of Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the invention was made in the course of their official duties with CSIRO; the nominated person is therefore entitled to the grant of the patent by virtue of Section 54(1) of the Science and Industry Research Act 1949.

Dated this 25th day of March, 1993.

KEN HAMILTON
Registered Patent Attorney

AU9175381

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HEAT PIPE

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(56) Prior Art Documents
US 4351388
US 3018087
GB 1355422

(57) Claim

1. A heat pipe in the form of a panel comprising an enclosed chamber having opposed generally planar parallel wall portions and filled with a liquid and a vapour of the liquid, the liquid and vapour being in equilibrium, the heat pipe being effective, in use, when a first said wall portion is heated, to transfer heat to a second said wall portion by transfer of vapour generated at said first wall portion to the second wall portion, the heat pipe being arranged and constructed whereby the vapour is condensed at said second wall portion and returned to said first wall portion, and distributed over said first wall portion, said first wall portion having means for effecting substantial distribution of returned said liquid over the interior surface thereof, the second wall portion not having such means at its interior surface and being arranged whereby, in

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the event that the first wall portion is cooler than the second wall portion, a relatively lesser degree of heat transfer to the first wall portion occurs by virtue of absence of means for effecting substantial distribution of said liquid over the inner surface of the second wall portion.

639775

COMMONWEALTH OF AUSTRALIA

The Patents Act 1952

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COMPLETE SPECIFICATION FOR THE INVENTION ENTITLED

HEAT PIPE

The following statement is a full description of the invention, including the best method of performing it known to us:

HEAT PIPE

This invention relates to heat pipes.

Heat pipes generally comprise an enclosed chamber, having opposed walls, and filled with a liquid and a vapour of the liquid, the liquid and vapour being in equilibrium, the heat pipe being effective in use, when a first said wall is heated, to transfer heat to a second said wall by transfer of vapour generated at said first wall to the said second wall, the heat pipe being arranged and constructed whereby the vapour is condensed at said second wall and returned to said first wall, and distributed over said first wall.

Provision of adequate cooling in electronic equipment and packages is of concern in the electronics industry. For small installations in remote inland locations, difficulty may be encountered in meeting the present upper temperature limit of 55°C air temperature in the enclosure that is specified by equipment suppliers to

prevent the electronic components overheating. The computer industry has had to resort to complex thermal conduction modules to dissipate the high thermal power densities from their arrays of microelectronic chips. The high rate of failures in avionic equipment in high performance aircraft is attributed to inadequate thermal power dissipation in the equipment. Although the actual power to be dissipated is small, only a few watts per chip in the latest main frame computers or telecommunications equipment, the surface area for dissipating the heat is also small, say $2 \times 10^{-5} m^2$ for the computer chip or $5 \times 10^{-4} m^2$ for the chip in the telecommunications equipment. If the effective surface area of the microelectronic chip could be increased, then the problem of its thermal energy dissipation would be greatly reduced.

The use of heat pipes to transfer heat from the components, such as electronic components is described in the publication "Heat Pipes" by P. Dunn and D. A. Reay (Pergamon Press, published in 1976). However, a problem exists in arranging the heat pipe in such a form that it is able to adequately contact the heat source. Although the heat pipe may have a flexible wall which is pressed against the component to be heated, the arrangement must then be such as to have a positive vapour pressure within the heat pipe, in use, whereby to ensure that the heat pipe is able to maintain its form. In many applications, however, it is desirable that the vapour pressure within the heat pipe be less then atmospheric. Rigid objects, such as sintered metal wicks may be positioned between the opposed walls of a heat pipe, to aid return of liquid to the heated wall.

~~In one aspect, the invention provides a heat pipe as first above described characterised in that at least~~

The effective use of heat pipes have been limited by the above and other problems associated with heat pipes. Accordingly, it is an object of the present invention to overcome or alleviate at least one of the prior art problems associated with heat pipes.

In one aspect, the invention provides a heat pipe in the form of a panel comprising an enclosed chamber having opposed generally planar parallel wall portions and filled with a liquid and a vapour of the liquid, the liquid and vapour being in equilibrium, the heat pipe being effective, in use, when a first said wall portion is heated, to transfer heat to a second said wall portion by transfer of vapour generated at said first wall portion to the second wall portion, the heat pipe being arranged and constructed whereby the vapour is condensed at said second wall portion and returned to said first wall portion, and distributed over said first wall portion, said first wall portion having means for effecting substantial distribution of returned said liquid over the interior surface thereof, the second wall portion not having such means at its interior surface and being arranged whereby, in the event that the first wall portion is cooler than the second wall portion, a relatively lesser degree of heat transfer to the first wall portion occurs by virtue of absence of means for

effecting substantial distribution of said liquid over the inner surface of the second wall portion.

In a preferred embodiment the chamber is filled with flowable and/or flexible porous material, such as a porous material which is compactible and which remains porous under compaction. The porous material may comprise a flowable particulate material. The porous material may permit the one wall to be deformed against a component, for good contact therewith whilst preventing deformation even when the vapour pressure is less that atmospheric, or less than the surrounding atmosphere.

The porous material is preferably formed of discrete particles, preferably rigid particles of small size such as 2.5 millimetres diameter and may for example comprise glass beads.

Both walls may be rigid or may be flexible. The space between the walls may be of relatively small dimension compared with the are of the walls, whereby the heat pipe is of generally planar configuration. The whole of the heat pipe may be conformable as a unit against the outer surface of a component with which heat is to be conducted.

Preferably, the means for distributing returned liquid comprises a wick which underlies the inner surface thereof. This may, for example, comprise a suitable fine gauze. To further aid in

wetting of the inner surface, the surface is preferably formed of a suitable metal such electro-deposited thereon. Suitable metals include copper and aluminium. If desired, depending in the orientations which the heat pipe is to adopt in use, the inner surface of the other wall may be similarly formed with a wick and formed of material which has good wettability properties, such as by deposition of metal thereon.

The invention generally contemplates that the heat pipe may be in the form of an envelope formed of a thin plastics sheeting coated in the inside with metal or other suitable wetting agent, which is capable of containing the liquid and vapour therewithin without substantial loss over long periods of time.

In another aspect, the invention provides an enclosure having a wall or ceiling or part thereof formed as a heat pipe effective to permit substantial heat transfer through the wall out of the enclosure when the interior of the enclosure adjacent the wall is at a higher temperature than the exterior temperature adjacent the wall, and to permit only a substantially lesser heat transfer through the wall into the enclosure from the exterior of the enclosure when the exterior of the enclosure adjacent the wall is at a higher temperature than the interior of the

enclosure adjacent the wall. The wall may be formed as a heat pipe constructed in accordance with the teachings of this invention. More particularly, the wall may include one or more upright panels, the or each such panel defining an enclosed chamber bound by opposed side wall portions and filled with a liquid and a vapour of the liquid, the liquid and the vapour being in equilibrium, and being effective in use, when one side wall portion of the panel is heated, to transfer heat to the other opposed side wall portion thereof, by transfer of vapour generated at said first wall portion to the second wall portion, the panel being arranged and constructed whereby the vapour is condensed at said second wall portion and returned to said first wall portion, and distributed over said first wall portion. In such case, the first wall portion is arranged to be innermost in the enclosure. Thus, the first wall portion has, adjacent the inner surface thereof, means for distributing the returned liquid thereover.

In another aspect, the invention provides a heat pipe as first above described and having a conformable envelope defining said walls. The pressure within the envelope may be less than atmospheric and means may be provided maintaining said walls separated.

The heat pipe of the invention may be used as a component in a heat transfer apparatus adapted fcr heat transfer of an enclosure with the surrounding atmosphere.

In another preferred embodiment the opposed walls may be dimpled or corrugated.

The invention is further described by way of example only with reference to the accompanying drawings in which;

Figure 1 is a perspective diagram, partly sectioned, of a heat pipe constructed in accordance with the invention, arranged for dissipating heat generated by electronic components on a circuit board;

Figure 2 is a perspective view like Figure 1 but illustrating a modified arrangement constructed in accordance with the invention;

Figure 3 is a perspective view of an experimental apparatus constructed in accordance with the invention;

Figure 4 is a graph illustrating the performance of the experimental apparatus of Figure 3 compared with other forms of cooling of electronic components;

Figures 5 and 6 are respectively a partly sectioned plan view and a cross section of an experimental apparatus;

Figure 7 is a graph illustrating comparative

performance of the invention;

Figure 8 is a perspective view of an enclosure constructed in accordance with the invention;

Figure 9 is a partially sectioned perspective view of a panel formed in accordance with the invention and forming part of the enclosure of Figure 8;

Figure 10 is a perspective view of space heating apparatus comprising an exemplary form of heat transfer apparatus constructed in accordance with the invention;

Figure 11 is a perspective view of a panel structure forming part of the apparatus of Figure 10 and constituting a heat pipe;

Figure 12 is a transverse cross-section of the panel structure of Figure 11;

Figure 13 is an enlarged transverse section of the panel structure of Figure 11; and

Figure 14 is a partly sectional perspective view of a modified form of heat pipe.

Figures 1 and 2 show a heat pipe 10 constructed in accordance with the invention. This is in the form of a generally planar enclosure 15 defining two opposed substantially planar walls 12, 14. The enclosure is formed of thin plastic material. The enclosure has on its inner surface, such as over the entirety thereof, but in this instance at least on the inner surfaces of the walls 12 and 14 a suitable metalised surface. The entirety of the inner surface of the enclosure is in contact with a planar wick 20 which is, in particular, positioned adjacent to the inner surfaces of the two walls 12 and 14. The wick may be formed by a suitable gauze material.

The pipe 10 has, within the enclosure 15, a central porous layer 22 formed in this instance from glass beads. The enclosure also has therewithin liquid, and a vapour of that liquid, the liquid saturating the wick and

coating the porous layer 22 and being in equilibrium with its vapour throughout the enclosure.

As shown, the enclosure 15 is positionable against an electronic circuit board 24, being positioned against the underside thereof in Figure 1 and against the upper side thereof in Figure 2. As shown, the upper side of the circuit board 24 carries electronic components 26. Because of the flexible nature of the walls 14 and 12, the wall which is pressed into conformity with the circuit board is capable of closely conforming to the surface contour of the board in Figure 1 or into conformity with the board and the associated components 26 as shown in Figure 2.

In use, local temperature differences on the surface of the enclosure 15 such as at the surface 12 which is in contact with the surface board 24 lead to vapour pressure differences within the device and a consequent transfer of vapour through the porous layer and away from that wall to the opposite wall 14, through the porous layer 22. The resultant mass transfer with phase change from liquid to vapour phase is such a strong heat transfer mechanism if one side of the device is in contact with a heat sink (such as being in contact with the atmosphere) and therefore at uniform temperature, every spot on the opposite side is reduced to nearly the same temperature, even though thermal energy may be being introduced locally. That is to say local heat produced by the devices 26 and applied directly to the surface of the wall 12 in Figure 1 or Figure 2 will be transferred to the whole of the area of the wall 14. Hence the whole surface area of the wall 14 becomes the effective area for dissipating energy from any one of the electronic components 26 on the board 24.

In most instances, the internal pressure within

the enclosure 15 will be below atmospheric pressure and hence the force exerted on the walls 12 and 14 will always be inwardly directed. However, the porous layer 22 will provide mechanical support for the walls, even when they are under compression so that the walls 12 and 14 themselves can be of light construction. Because the layer is flowable it permits the envelope to readily deform and conform itself to the shape of the circuit board 24 and associated components 26. The compaction properties of the layer 22 prevent collapse of the envelope under these conditions, however.

The metallisation of the inner surfaces of the walls 12 and 14 provides a good wetting surface to ensure that liquid drawn along by the wick 20 is in good contact with the walls. The wick 20, as described, provides liquid to any hot spot to replace the mass loss by evaporation at that spot. The metallising of the plastic also helps to prevent atmospheric gases from diffusing into the device through the walls.

If the porous material is itself wettable, such as being formed of the described glass beads, it too will transfer liquid from the condensing surface, i.e. the inner surface of wall 14, back to the heat source. Furthermore, since there will be a pressure and temperature gradiant throughout the porous layer, condensation will occur within the porous layer and thus improve the return of liquid to the heat source. The utilisation of thin plastic for the walls 12 and 14 allows the condensing surface to have a complex shape. It has been found that this does not significantly degrade the vapour transfer rate from the source and allows the condensing surface to be optimised for heat transfer to the external medium.

OPERATION THEORY

Consider a 50 mm x 10 mm microelectronic chip mounted on a 300 mm x 150 mm card and dissipating 1W., the chip having 40 pins and being mounted in a socket with each pin and socket connector being 1 mm wide and 0.1 mm thick. If the length of each pin is 4 mm and each socket connector is 3 mm, these give a combined length of 7 mm. The contact resistance between the socket and pin is assumed to be zero and any resistance through the solder which fills the hole in the card at each socket connector is ignored; the cross-sectional area of the solder will therefore be much greater than that of the pin.

If the flux is dissipated entirely through the top surface of the electronic component (such as an electronic chip area 500 mm^2) by natural convection to the atmosphere, then the surface of the chip will be 200 K above the atmospheric temperature. This assumes a heat transfer coefficient of 10 $W.m^{-2}.K^{-1}$.

If the flux is dissipated entirely through the 40 pins to the back of the card, then taking the conductivity of the pins to be that of copper, (385W $m^{-1}.K^{-1}$), then the temperature drop along each pin and connector is 4.5 °K. If the solder has a diameter of 2 mm and the convective transfer coefficient is 10 $W.m^{-2}.K^{-2}$, then the temperature of the solder above that of the air is 706 °K.

Both values give chip temperatures far above a reasonable maximum value of 90°C, for any reasonable ambient temperature.

By use of a heat pipe according to the invention, the flow of vapour will be through the porous medium and therefore governed by Darcy's law as follows;

$$\text{grad } P = -\frac{\mu}{\kappa}\underline{v}$$

where P is pressure, μ is viscosity, κ is permeability and $\underline{V}$ is velocity. For one-dimensional flow, the heat flow over an area A is

$$\dot{q} = L \rho A V$$

where L is the latent heat of vapourisation and ρ is density. The pressure drop ΔP over a length of ℓ is then

$$\Delta P = \frac{\mu}{\kappa} \frac{\dot{q} \ell}{L \rho A}$$

The permeability is given by

$$\kappa = \frac{d^2}{36 k_o} \frac{\phi^3}{(1 - \phi)^2}$$

where d is the diameter of the particles of the porous medium, ϕ is the void fraction and k_o has the value of 4.8 if the particles are spherical. For water, μ = 1.07 x 10^{-5} Pa.s, L = 2400 $kJ.kg^{-1}$, and if the condensing surface is at 48°C, ρ = 0.076 $kg.m^{-3}$.

If the porous medium is 2 mm spheres with a void fraction of 0.35, then $\kappa = 2.3 \times 10^{-9}\ m^2$.

For heat pipe 10 mm thick, that is, ℓ = 0.01 m, then if q is 1 W,

$$\Delta P = \frac{0.024}{A}\ \text{Pa}$$

If we take A to be the area of the circuit board 24 (0 045 m^2,) then $\Delta P = 0.5$ Pa; if A is the area of the chip (0 0005 m^2,) then $\Delta P = 48$ Pa; if A is the area of the solder, (0.000126 m^2), then $\Delta P = 191$ Pa. From steam tables the vapour pressure at 48°C is 11160 Pa and at 50°C 12340 Pa, giving a linear gradient of 1.7×10^{-3} $K.Pa^{-1}$. Hence the temperature drop would be 8.7×10^{-6} K, 7.8×10^{-4} °K and 3.1×10^{-2} °K for the above three areas respectively. These temperature differences are the upper and lower limits for the temperature drop across the area multiplier.

Insofar as operating effectiveness is concerned, the worst case occurs by ignoring any wicking properties of the porous medium and assuming the liquid to return to the heat source only via the wick from the condensing surface. Assume the height of the multiplier is 150 mm, the heat source is 75 mm above the bottom, and all condensation is occurring at a height of 75 mm on the condensing surface. Take the wick as a standard heat pipe wick consisting of two layers of 200 mesh woven wire with an aperture of 0.08 mm, wire diameter of 0.045 mm and 41% open space. If the wick is 0.09 mm thick, then a width of 2 mm is sufficient to carry the liquid flow necessary to transfer 1 W from the source to the condenser.

The power density at the source will be limited by the formation of vapour bubbles within the wick. Dry-out in the wick occurs when the pressure driving force needed to force the vapour from the liquid-vapour interface within the wick exceeds the maximum pressure that can be asserted by the liquid and capillary forces at that interface. Experimental values in excess of 1

$MW.m^{-2}$ are reported in the literature for both screen and groove wicks. In the example given above, if 1 W is dissipated entirely through the top surface then the power density is 2 kW m^{-2}, and if it is dissipated entirely through the pins then the power density in each pin is 250 $kW.m^{-2}$. The latter figure would be reduced to 8 kW m^{-2} at the solder if the solder has a diameter of 2 mm. These values are well below the 1 MW m^{-2} quoted above.

EXPERIMENTAL EXAMPLE 1

An experimental apparatus, sketched in Figure 3, has been constructed to demonstrate the principle of the invention. The heat source is a transistor 60, capable of dissipating 40 W through a copper base plate 60a which is electrically connected to the junction. The transistor is potted in epoxy resin and mounted in an opening in a plastic base 62 such that the copper base plate of the transistor forms a level surface with the plastic base of a heat pipe 70. The sides of the heat pipe 70 are of plastic but the top is a copper plate 76, which can be maintained at a chosen temperature by passing hot water through a serpentine tube (not shown) on its external surface. The inside of the heat pipe 70 was lined with a cloth wick 72 and filled with 2.5 mm diameter glass spheres 74. Its overall dimensions were 200 mm x 200 mm x 10 mm and the copper plate of the transistor is 6 mm x 7 mm. The use of plastic for the base and sides of the multiplier ensured that the conduction through them from the transistor to the isothermal heat sink is negligible.

The heat pipe 70 was filled with 200 ml of distilled, de-gassed water and then connected to a vacuum pump, which withdrew 140 ml of liquid water from the heat pipe. The remaining 60 ml was bound to the wick and the glass spheres through surface tension and could only have

been removed as vapour. Unfortunately, the multiplier could not be completely sealed and over a period of 30 minutes the vacuum decreased from 12 torr, which was the saturation vapour pressure of the water, to 18 torr, indicating a slow air leak.

Experiments were performed with the apparatus horizontal and vertical filled with air or with liquid water at a pressure of one atmosphere, and partially filled with water. In this last case the remaining volume was occupied with vapour and some air. The results are given in Figure 4, which shows the temperature difference between the source and the isothermal plate 76, plotted against the power supplied to the source. To try to overcome the effect of the air leak, the pressure was reduced and the temperature of the source monitored for fifteen minutes. The temperature did not change over this period and the results are shown by the two crosses at 0.2 W and 0.4 W on the abscissa in Figure 4. The heat pipe was vertical for these two points and they show that if the air is removed, then the temperature difference between the source and the isothermal plate is negligible. The results for a prior art thermal conduction module are also shown in Figure 4 and clearly this heat pipe has a superior performance. This prior art module was of the kind described by OKTAY, S., HANNEMANN, R. and BAR-COHEN, A. in an article entitled "High Heat from a Small Package", Mechanical Engineering, March 1986, pp. 36-42.

EXPERIMENTAL EXAMPLE 2

A further experimental apparatus is shown in diagrammatic form in Figures 5 and 6. A transistor heat source 90 was soldered to a 0.1 mm copper shim 92 extending over the base of the multiplier; copper was used for this surface because it is readily wettable when

cleaned and allowed a phosphor-bronze wick to be used. The shim 92 is positioned over a plastics base 94 which together with the shim 92 forms wall 14 of the heat pipe 10. The opposite wall 12 is formed by a copper plate 95. An annular plastics ring 96 forms an edge wall of the heat pipe. Within the ring 96 and between the shim 92 and plate 94, there is positioned the wick 20 which is in the form of an envelope containing the porous layer 22.

Experimental results for this version of the area multiplier are shown in Figure 7, in which thermal resistance is plotted against electrical power supplied to the transistor heat source. The resistance across the multiplier alone, as well as from the source to the multiplier thermal sink, is shown when it was operated in both horizontal and vertical positions. Data are also shown for IBM and Mitsubishi thermal conduction modules as described in the aforementioned publication "High Heat from a Small Package" by Oktay, Hanneman and Bar-Cohen. The area multiplier has a superior performance even when the contact resistance of the source is included.

The described heat pipe is capable of dissipating thermal energy from a small source of high flux density to a large sink with a consequent low flux density, for a very small temperature difference between the source and the sink, using, as a mechanism for heat transfer, vapour flow through a porous medium.

If the porous medium 22 is wettable, then it will provide some wicking back to the source and it may be possible to dispense with some or all of the wick 20.

Particularly where the heat pipe is operated with the wall 14 at which condensation occurs uppermost the wick 20 may not need to be provided adjacent that wall.

As an alternative to providing the wick 20 the

inner surface of one or both walls 12, 14 may be formed with channels which act as a wick.

The form of construction described allows the large cooling surface to have a complex shape to enhance the heat transfer from the multiplier to the external cooling fluid; for example, cooling to the atmosphere by natural convection. The form of construction also allows a flexible heat pipe to be constructed so that these can be interconnected.

Heat pipes formed in accordance with the invention may be used for cooling components on electronic circuit boards.

Other applications include cooling heat sources within sealed equipment by providing a low resistance between the source and the sides of the container, which can also be lined with multipliers. If the surface area of the container does not provide adequate cooling, then folding flaps constructed as a heat pipe of this invention can be used to increase the area; this could be beneficial in cases where cooling by natural convection alone is required.

The heat pipe of the invention may also possibly replace the fin in a conventional tube and fin heat exchanger; for example, replacing the condenser heat exchanger on a refrigerator or panel radiators.

A further alternative arrangement is to provide apparatus substantially as in Figure 3, but positioned vertically and with the heat source located at the bottom. In this case, no wicking is required.

Generally since the heat pipe of the invention provides an essentially isothermal surface, it can be applied to those circumstances where temperature uniformity is desired such as ovens.

Whilst in the described arrangements the opposed walls 12

and 14 are planar and parallel, this is not essential. For example the wall at which, in use, cooling occurs, may be differently shaped to assist heat dissipation.

Furthermore, whilst the described arrangements have been described in the context of heat Jissipation from point sources, that is to say in the context of use as an area multiplier, the heat pipes of the invention are in principle usable in the reverse situation to conduct heat from a large source of low flux density to a small source of high flux density. An example of use of this type is to be found in refrigerator evaporator systems.

Figure 8 shows an enclosure 100 having side walls and a roof formed from a plurality of panels 102. The enclosure may be of any size, but, in the particular application described here, is intended to form a small building, such as a portable or demountable building. The panels 102 may, in this instance, be of dimension of the order of half a meter high by a meter in width. As shown in Figure 9, each panel 102 is formed with two parallel opposed side wall portions 104, 106 sealed around the edges thereof such as by suitable edging 108 which may, for example, be welded to the wall portions 104, 106. A closed interior chamber 114 is thus formed in the panel. Its preferred that at least the edging 108 be relatively rigid so as to impart some structural rigidity to the panel. The wall portions 104, 106 may be sufficiently rigid to maintain the wall portions in spaced parallel relationship, notwithstanding that there is some pressure differential as between the exterior of each wall and the interior thereof because of existance of a relatively low pressure condition in chamber 114. Alternatively, or additionally, the wall panels may be maintained in spaced apart relationship by the presence of a flowable and/or flexible porous material 110 therewithin, such as

previously described. Such material may, for example, be in the form of glass beads.

On the interior surface 106a of wall portion 106 there is provided a wick 112 of planar configuration. As previously described, this may be formed of a suitable gauze material. The chamber 114 has therewithin a liquid and a vapour of that liquid. The liquid saturates the wick 112 and saturates the material 110. As before, the liquid is in equilibrium with its vapour throughout the chamber. There is no wick like the wick 112 adjacent the inner surface 104a of the wall portion 104.

The panels 102 are arranged in the enclosure 100 with wall portions 106 innermost, in each instance. In consequence, under the circumstance where the interior of the enclosure 100 is at a higher temperature than the exterior thereof, the wall portion 106 of each panel will be at a higher temperature than the wall portion 104 thereof. Then, liquid within the chamber 114 is evaporated at that surface and condensed on the cooler wall 104, at the inner surface 104a thereof, thence running to the foot of the chamber 114. The liquid is returned to the inner surface 106a by the wick 112 which, additionally, acts to distribute the liquid thereover. Thus, under the described condition where the interior of the enclosure 100 is at a higher temperature than the exterior thereof, effective heat transfer may take place from the interior to the exterior of the enclosure.

Under the condition where the exterior of the enclosure 100 is at a higher temperature than the interior thereof, although some liquid may be evaporated at the inner surface 104a of the wall portion 104, and a small quantity may condense against the inner surface 106a of wall portion 106, access to surface 106a is obtained only through the wick 112 which wick inhibits return of the

liquid to the pool of liquid at the base of the chamber 114. More importantly, since there is no means for returning liquid to the surface 104a of wall portion 104, no substantial amount of liquid is available at the surface 104a for such evaporation and transfer to the wall 106. In this fashion, then, each panel 102 constitutes a thermal diode which although permitting outflow of heat from the enclosure 100, under the condition where the interior of the enclosure is at a higher temperature than the exterior thereof, inhibits flow of heat from the exterior of the enclosure to the interior thereof, under the condition where the exterior is at a higher temperature than the interior, so that the panels 102, in the latter instance, act substantially as heat insulators.

Enclosures such as the described enclosure 100 are useful under certain weather conditions. For example in a desert, the days are usually very hot and the evenings quite cold. Thus, heat accumulated in the interior of an enclosure 100 positioned in a desert environment, during the day, may be dissipated through the side walls and roof thereof during the evening by virtue of the temperature outside the enclosure then being less than the temperature inside. On the other hand, during the day, the walls are substantially insulative and tend to minimize heat transfer into the interior of the enclosure.

Panels 102 constructed in accordance with the invention may, however, be used in any application where advantage derives from the unidirectional nature of permitted heat flow therethrough.

In the described embodiments the glass beads may of course be replaced by other materials. Generally, particulates of any material of some hardness and compression strength are suitable. Alternatively, for

example, sand may be employed. Where particulates are employed, the material from which the particles are formed need not be completely rigid and resilient materials, such as resilient beads, may be employed.

Also, flexible porous foam-like materials exibiting at least some resilience may be employed. Generally, any material may be employed which forms a porous body so long as the so-formed body is capable of bodily deformation and exibits adequate compaction properties, so as to prevent total local bodily collapse under application of the compression forces involved. Where the walls of the heat pipe are sufficiently rigid, it is not essential that the porous material exibit these properties, however. The material may also be in the form of a flexible mesh such as a plastics mesh with mesh openings of, for example, 1 cm square. Several layers of mesh may be overlaid, possibly differently oriented.

The heating apparatus 210 shown in Figure 10 comprises panel structures 212 each having two opposed side walls 214, and 216. These walls are generally planar over most of their areas, to each form a rectangular panel 213. Walls 214, 216 are joined at adjacent side edges, such as by an edge wall 218. At one edge of the panel 213, the panel structure 212 is conformed to a part cylindrical form to form a clip structure 220. The clip structure is designed to enable the panel structure 212 to be clipped to a heat transfer pipe 222 shown in Figure 10 and forming part of apparatus 10. This clipping is effected in the fashion shown in Figure 12, particularly.

Within the panel structure 212, including the clip structure 220, there is defined a closed chamber 224 which contains a small quantity of a suitable liquid such as water in equilibrium with vapour thereof. At the inner surfaces of the walls 214, 216, the walls are provided

with wicks 228 extending over substantially the whole thereof. The wicks may be formed of suitable gauze, for example, and are provided to draw liquid from a pool 230 thereof formed at the lowest most end of the apparatus up the internal faces of the walls 214, 216 where these define panel 213.

Heated fluid, such as water may be passed through the pipe 222 and thus causes heat transfer via the structures 220 to the panels 213 of the panel structures 212. The panel structures 212 comprises heat pipes in that heat is readily and rapidly transferred from the outer surfaces thereof to atmosphere. In particular, localised heating of the panel structures 212 such as in the region of the clip structure 220 where this is in contact with pipe 222 is effective to raise the temperature of correspondingly located inner surface portions of the walls 214 or 216 to cause evaporation of liquid thereat, the evaporated liquid then condensing at a region of lower temperature, such as on another internal surface portion of one of the walls 214 or 216. The condensed liquid runs, such as by a gravitational action, down the inner surface of the or each walls 214, 216 to collect at the pool 230 for re-transfer to the surfaces of the walls 214, 216 by the described wicking action.

Although, in the described arrangement, the wicks are provided at inner surfaces of each of the walls 214, 216, this is not essential and a single wick may, for example, be provided only at the inner surface of one of the walls 214, 216. In other cases the wicks may be dispensed with, or the or each wick replaced by other means effective to distribute liquid from pool 230 over part at least of the inner surface of one or both walls 214, 216.

The walls 214, 216, may be formed of substantially rigid material able to withstand substantial pressure differential as existing between the chamber 224 and the outside atmosphere since, generally speaking, the pressure within the chamber will be substantially less than atmospheric due to the requirement that the liquid therewithin being in equilibrium with its vapour (the vapour pressure generally being low). Alternatively, the walls may be formed of material not possessing such rigidity, steps being taken to maintain the walls in spaced relationship, such as by providing "dimples" 240 in the surfaces thereof as shown in Figure 11 and 12 or by corrugating the walls or by filling the chamber 224 with suitable material such as small spheres as previously described herein.

While, as shown, the heat pipes formed by the structures 212 include the clip structures 220, this is not essential and since, generally, some difficulty may be experienced, in manufacture, in conforming the side walls 214, 216 in parallel spaced relationship to form the clip structure 220, it is possible to alternatively simply form the heat pipe as a panel 213 with separate clips instead of the clip structure 220. Desirably, these clips should be formed of material of good thermal conductivity.

As shown, the apparatus 210 is arranged so that the panel structures 212 are upright with panels 213 extending upwardly from the pipe 222. This is not essential, however since each panel may be arranged at any desired angular disposition.

In the described arrangement, the apparatus 210 provides a ready means for transferring heat from the pipe 222 to the atmosphere, for space heating purposes. In particular, for space heating of a house, for example, it would merely be necessary to run hot water piping along, say, the lower part of selected walls, whereafter the panel structures 212 could simply be removably affixed to the pipe as desired. This has a particular advantage since, as shown, the panel structures are demountable from the pipe 222 and thus could be shifted by the user in accordance with asthetic dictates or to ensure best heating results. The arrangement is also suitable for cooling purposes in which case the pipe 222 would have cooled fluid passed therethrough. In such case, it may be preferable to suspend the panel structures 212 from the pipe, that is to say arrange them so that the panels 213 depended from the pipe rather than extend upwardly therefrom as shown.

In Figure 14, there is shown a heat pipe of similar form to that shown in Figure 2. Like reference numerals denote like components in Figures 2 and 14. In Figure 14, the wall 14 of the heat pipe has protuberances 84, in this case in cone-like form, in order to provide an extended heat transfer surface. Such heat transfer surface of extended area may be provided in other ways, such as by providing fins or cylindrical or other projections on the wall 14.

The heat pipe may be used for transfer of heat to an object having a shape to which the opposite wall 12 of the heat pipe is conformed, or for transfer to such object via the conformed wall 12. The wall 12 may be flexible and so conformed by contact with the object, or may be pre-formed, such as pre-moulded, to such form. Generally,

heat transfer may also be effected to and from parts of the heat pipe exterior which may or may not coincide with the walls 12, 14. Particularly, such heat transfer may be effected to an edge of the heat pipe. Usually, as shown, a suitable wick or other liquid distribution device is provided over the inside surfaces of the walls 12, 14, but could be provided at either wall only, or at one or more edge wall portions joining the peripheries of walls 12, 14.

The described construction has been advanced merely by way of explanation and many modifications may be made thereto without departing from the spirit and scope of the invention as defined in the appended claims.

The claims defining the invention are as follows:

1. A heat pipe in the form of a panel comprising an enclosed chamber having opposed generally planar parallel wall portions and filled with a liquid and a vapour of the liquid, the liquid and vapour being in equilibrium, the heat pipe being effective, in use, when a first said wall portion is heated, to transfer heat to a second said wall portion by transfer of vapour generated at said first wall portion to the second wall portion, the heat pipe being arranged and constructed whereby the vapour is condensed at said second wall portion and returned to said first wall portion, and distributed over said first wall portion, said first wall portion having means for effecting substantial distribution of returned said liquid over the interior surface thereof, the second wall portion not having such means at its interior surface and being arranged whereby, in the event that the first wall portion is cooler than the second wall portion, a relatively lesser degree of heat transfer to the first wall portion occurs by virtue of absence of means for effecting substantial distribution of said liquid over the inner surface of the second wall portion.

2. A heat pipe as claimed in claim 1 wherein said chamber is filled with flowable and/or flexible porous material.

3. A heat pipe as claimed in claim 2 wherein said walls are maintained apart by the porous material.

4. A heat pipe as claimed in claim 3 wherein said porous material comprises flowable particulate material.

5. A heat pipe as claimed in claim 2 or 3 wherein one or both said wall portions are dimpled or corrugated to maintain the wall portions spaced apart over at least substantial parts of the areas thereof.

6. A heat pipe as claimed in claim 1 wherein said heat pipe has rigid walls.

7. A heat pipe as claimed in any one of the preceding claims wherein said means for effecting substantial distribution of returned said liquid over the interior surface of said first wall portion comprises wicking means located adjacent said inner surface of said first wall portion.

8. A heat pipe as claimed in claim 7 wherein said wicking means comprises a woven metallic mesh, a cloth wick or a fine gauze.

9. A heat pipe as claimed in any one of the preceding claims wherein the pressure inside the panel is below atmospheric pressure.

10. An enclosure having a wall or ceiling or part thereof formed as a heat pipe, the heat pipe comprising at least one panel, wherein the one or each such panel defines an enclosed chamber having opposed generally planar parallel wall portions and filled with a liquid and a vapour of the liquid, the liquid and the

vapour being in equilibrium, and being effective in use, when a first wall portion of the panel is heated, to transfer heat to the second opposed wall portion thereof, by transfer of vapour generated at said first wall portion to the second wall portion, the panel being arranged and constructed whereby the vapour is condensed at said second wall portion and returned to said first wall portion, and distributed over said first wall portion said first wall portion having means for effecting substantial distribution of returned said liquid over the interior surface thereof the second wall portion not having such means at its interior surface and being arranged whereby, in the event that the first wall portion is cooler than the second wall portion, a relatively lesser degree of heat transfer to the first wall portion occurs by virtue of absence of means for effecting substantial distribution of said liquid over the inner surface of the second wall portion.

11. An enclosure as claimed in claim 10 wherein the means for distributing the returned liquid comprises wicking means.

12. An enclosure as claimed in claim 11 wherein said wicking means comprises a woven metallic mesh, a cloth wick or a fine gauze.

13. An enclosure as claimed in any one of claims 10 to 12 wherein a relatively low pressure condition exists in the chamber.

14. An enclosure as claimed in any one of claims 10 to 13 wherein the chamber is filled with a flowable and/or flexible porous material.

15. An enclosure as claimed in claim 14 wherein the said porous material comprises flowable particulate material.

16. An enclosure as claimed in any one of claims 10 to 15 wherein said opposed side wall portions are rigid.

17. An enclosure as claimed in any one of claims 10 to 16 wherein at least one of said first wall portion or said second wall portion are corrugated or dimpled.

18. An enclosure as claimed in any one of claims 10 to 17 wherein the first wall portion is arranged to be innermost in the enclosure such that substantial heat transfer out of the enclosure occurs when the interior of the enclosure adjacent the first wall portion is at a higher temperature than the exterior temperature adjacent the second wall portion, and only a substantially lesser heat transfer into the enclosure from the exterior of the enclosure occurs when the exterior of the enclosure adjacent the second wall portion is at a higher temperature than the interior of the enclosure adjacent the first wall portion.

19. An enclosure as claimed in any one of claims 10 to 18 wherein the enclosure comprises a room, a portable building or a demountable building.

20. A heat pipe substantially as hereinbefore described with reference to Figure 9.

21. An enclosure substantially as hereinbefore described with reference to Figure 8.

DATED THIS 27TH DAY OF MAY, 1993

COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION

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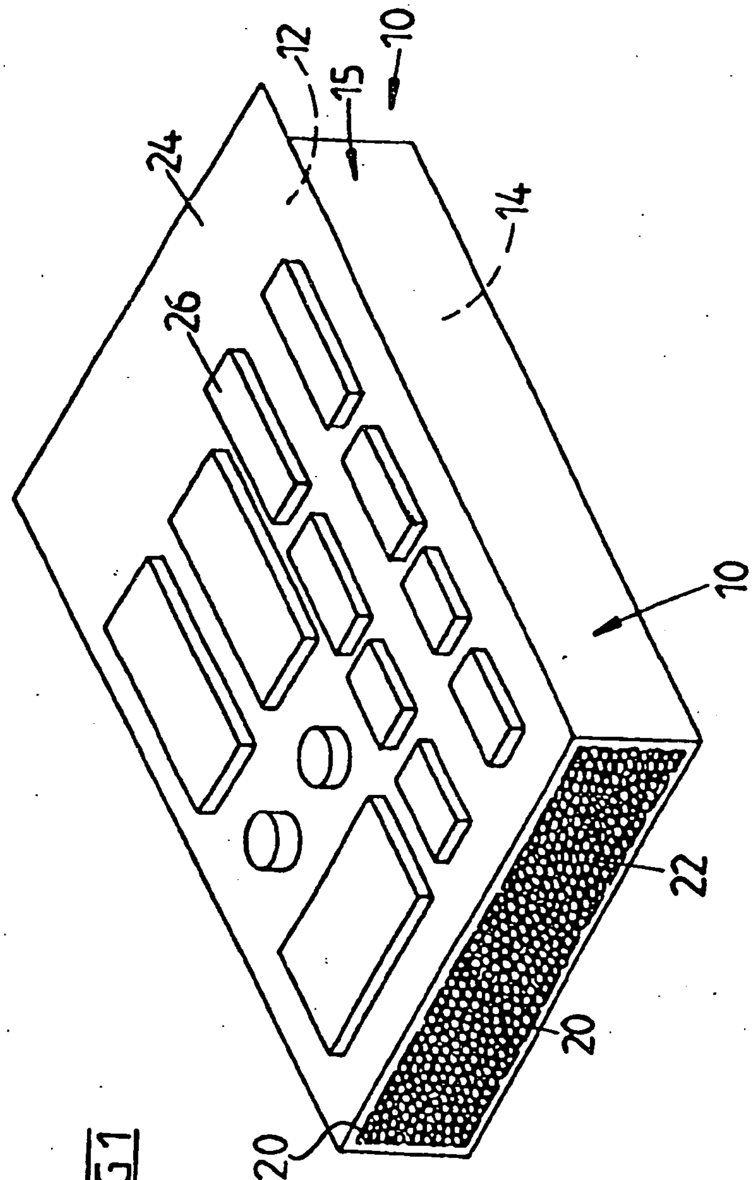

FIG 1

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24. 4. 91 75381

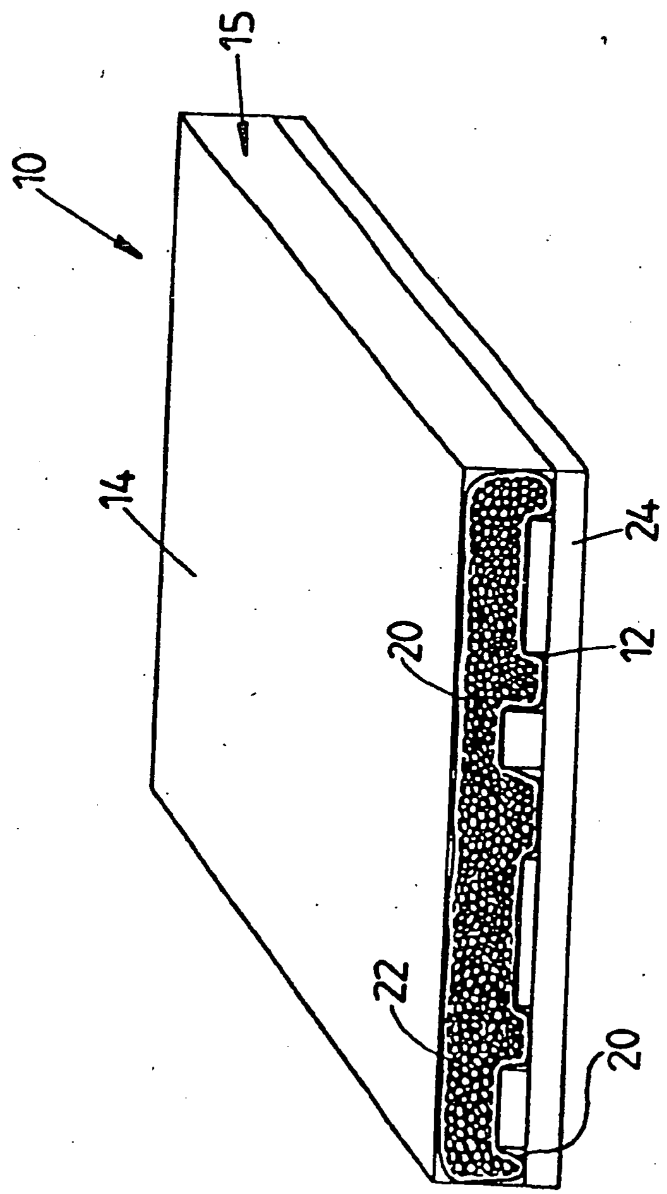
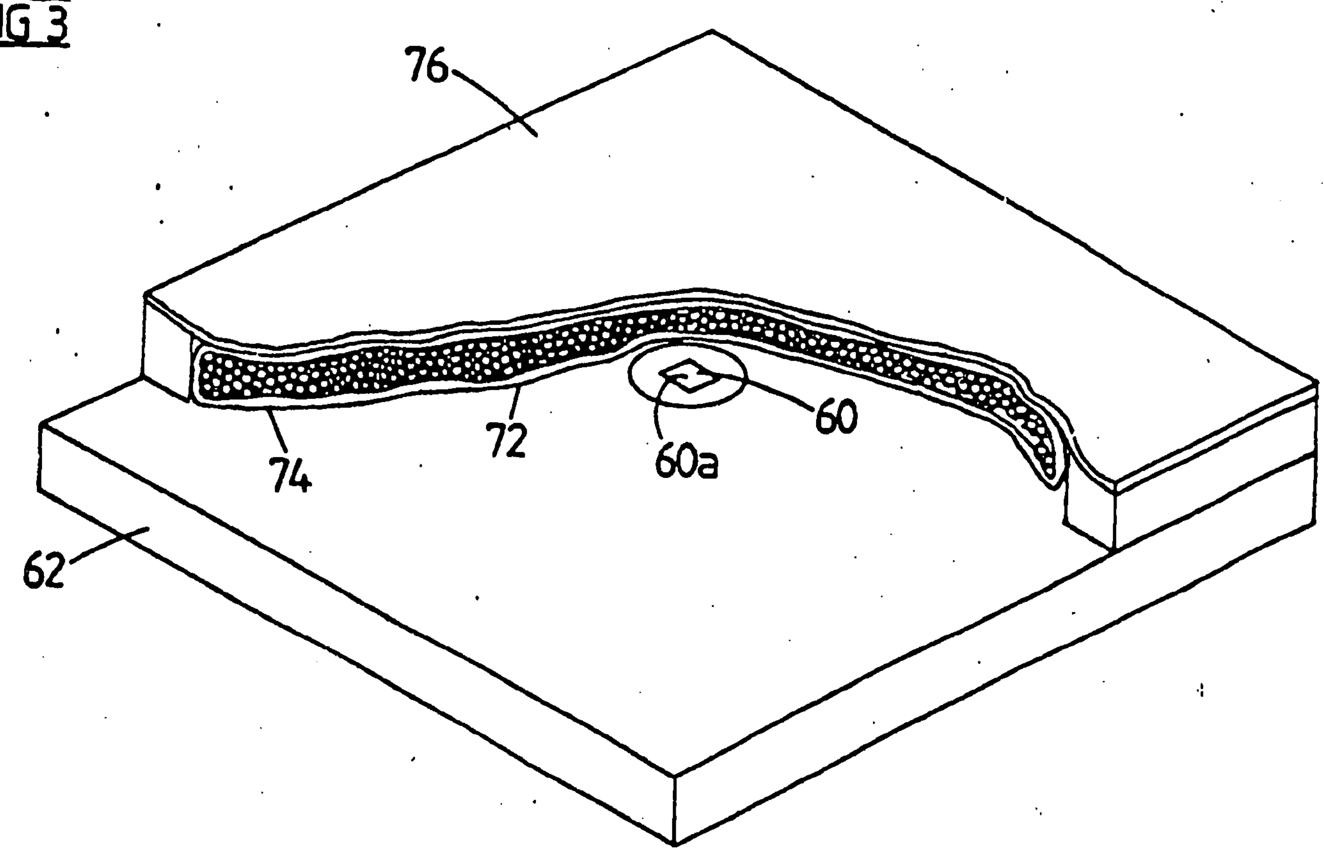
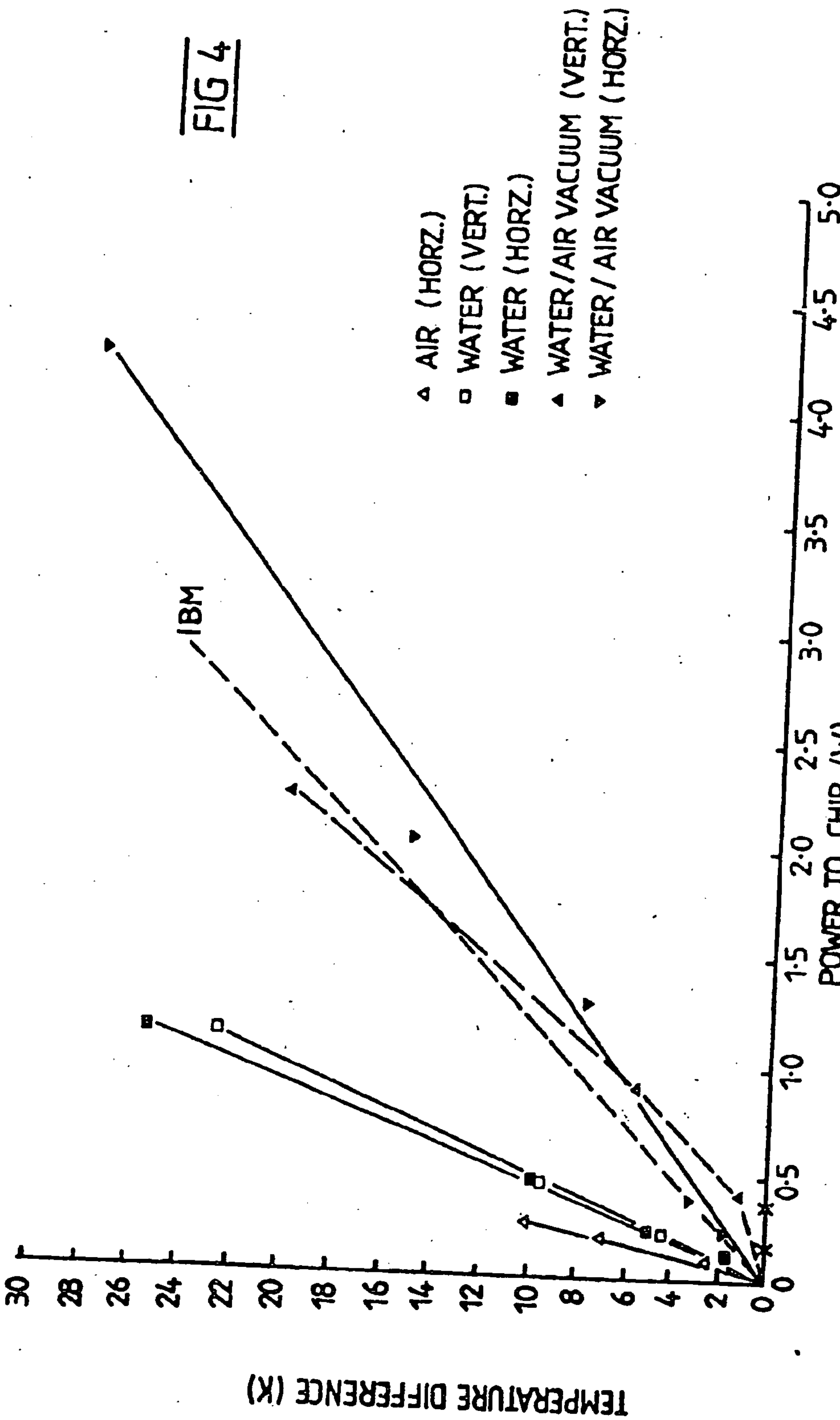


FIG 2

24 491 75301

FIG 3





AIR (HORZ.)
WATER (VERT.)
WATER (HORZ.)
WATER/AIR VACUUM (VERT.)
WATER/AIR VACUUM (HORZ.)
IBM
POWER TO CHIP (W)
TEMPERATURE DIFFERENCE (K)
0
0·5
1·0
1·5
2·0
2·5
3·0
3·5
4·0
4·5
5·0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

FIG 4

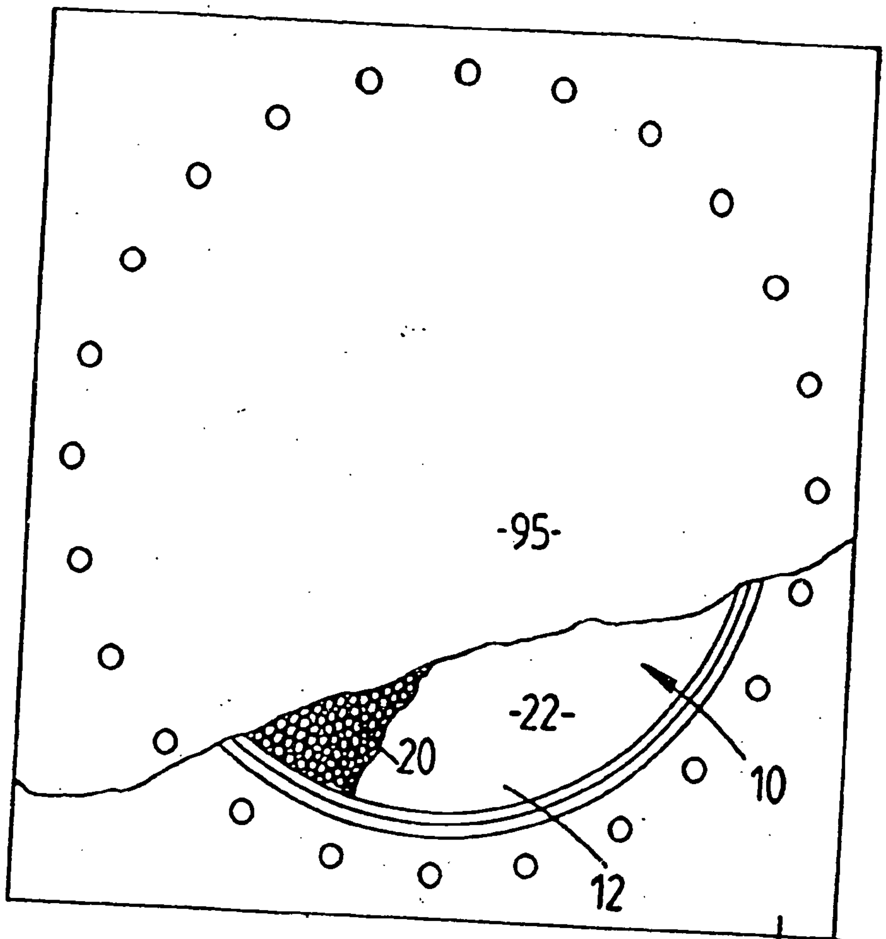


FIG 5

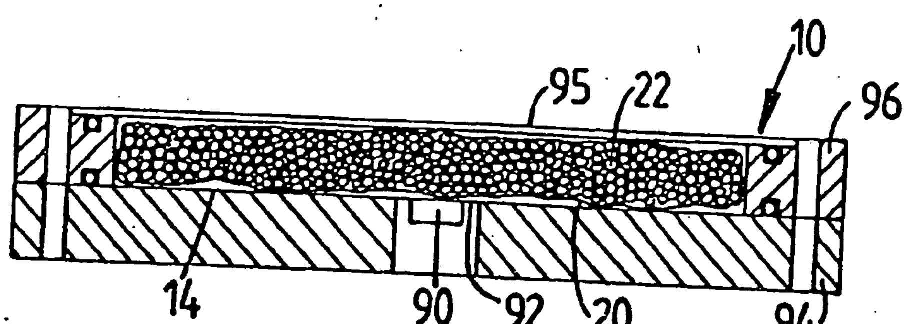


FIG 6

FIG 7

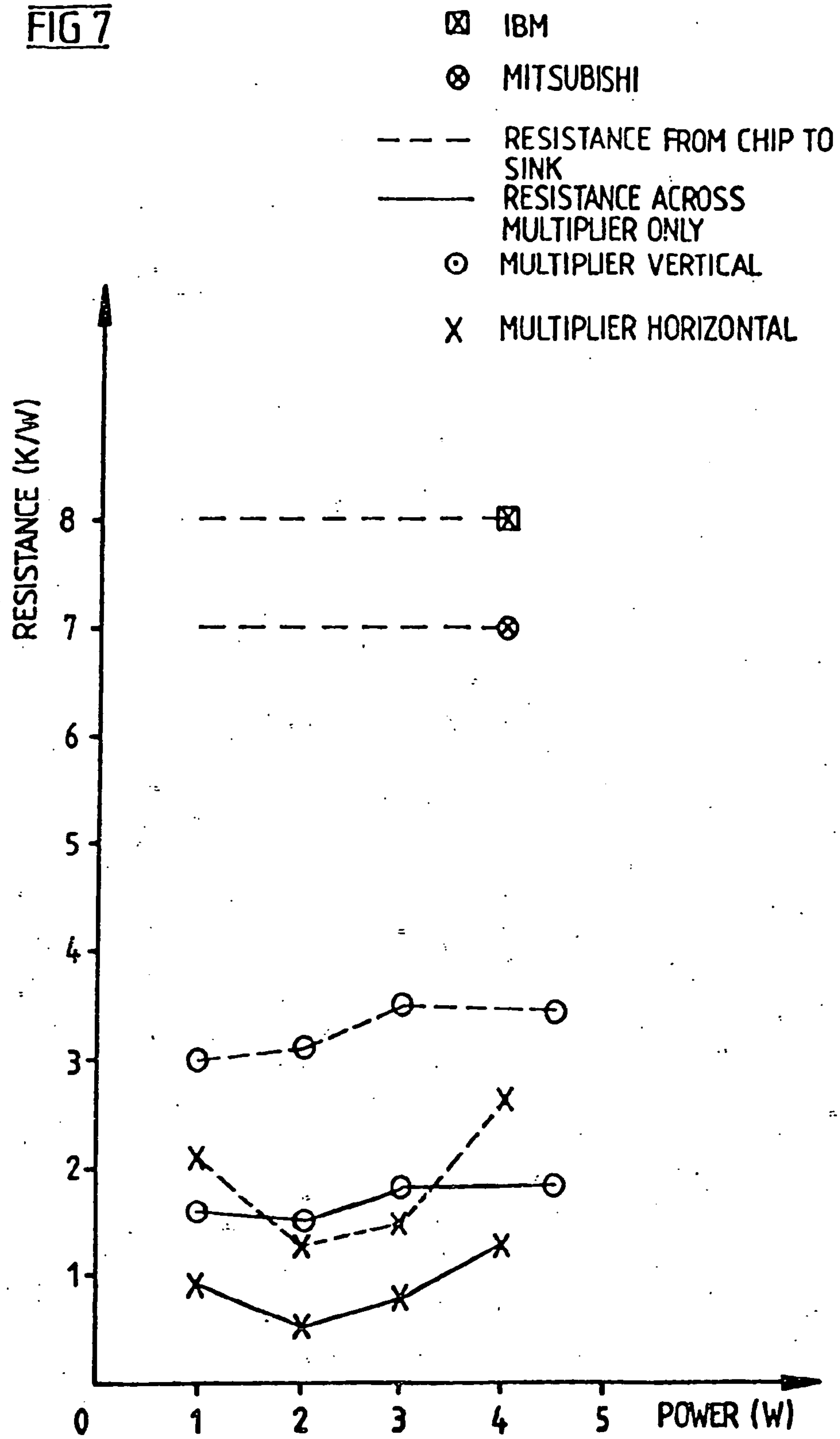
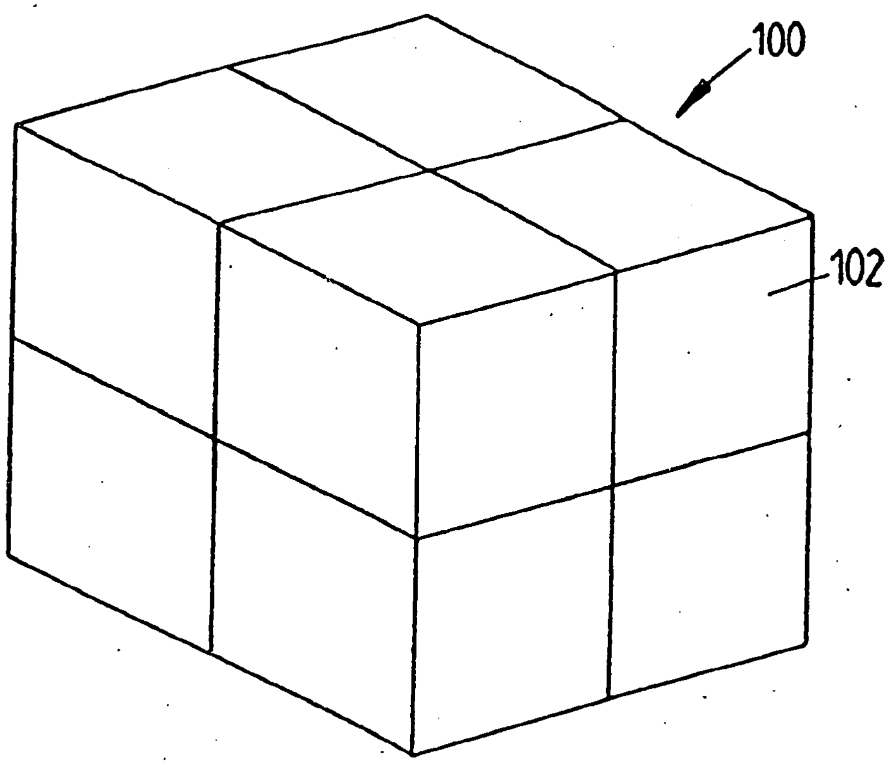

IBM
MITSUBISHI
RESISTANCE FROM CHIP TO SINK
RESISTANCE ACROSS MULTIPLIER ONLY
MULTIPLIER VERTICAL
X MULTIPLIER HORIZONTAL
RESISTANCE (K/W)
8
7
6
5
4
3
2
1
0
1
2
3
4
5
POWER (W)

FIG 8



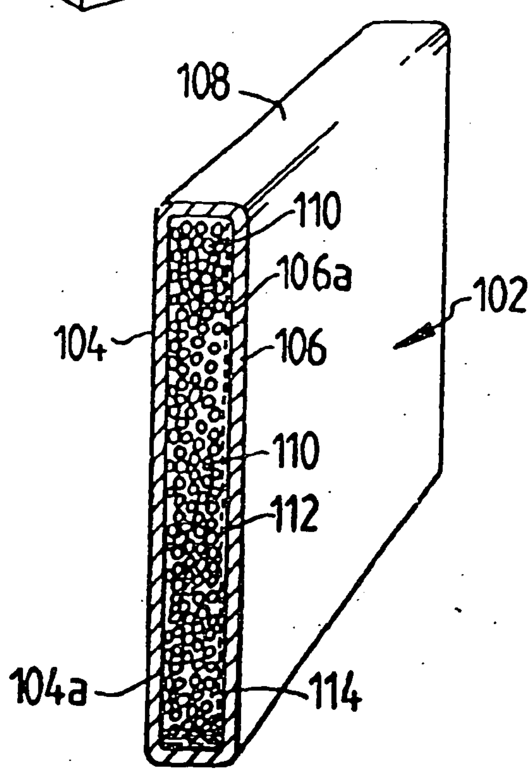


FIG 9

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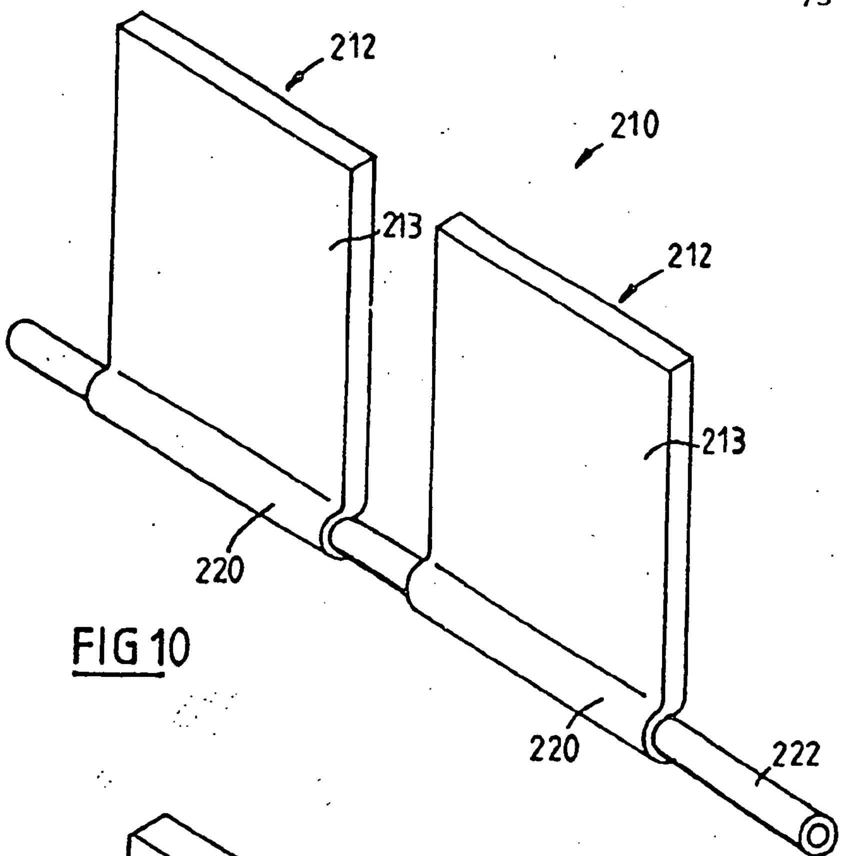

FIG 10

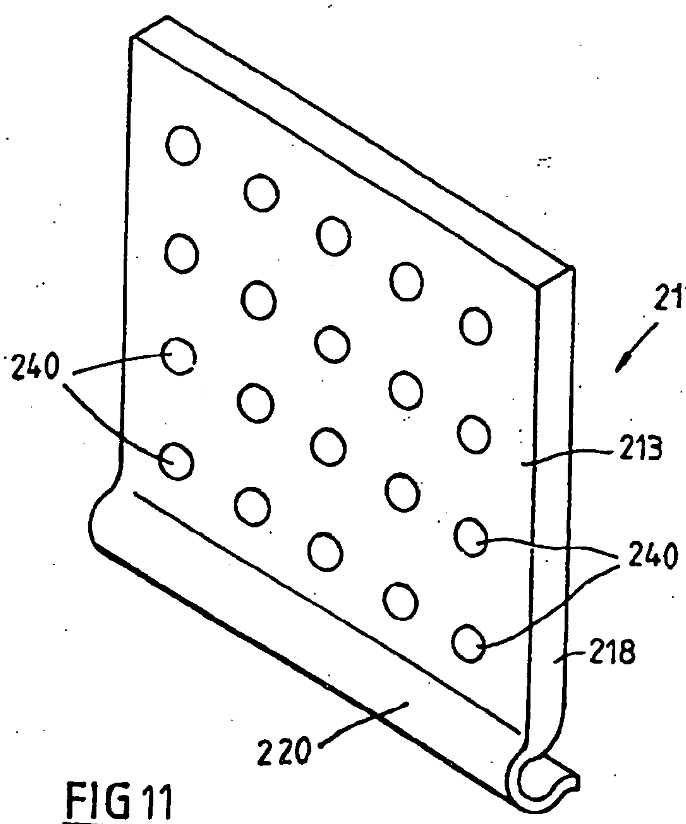

FIG 11

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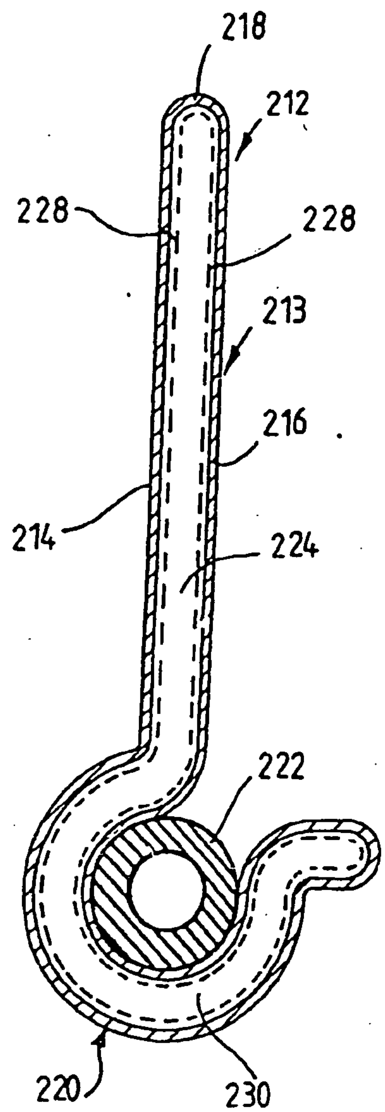
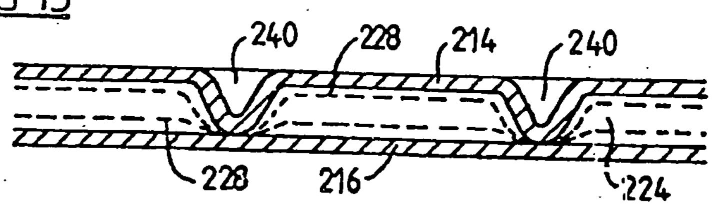


FIG 12

FIG 13



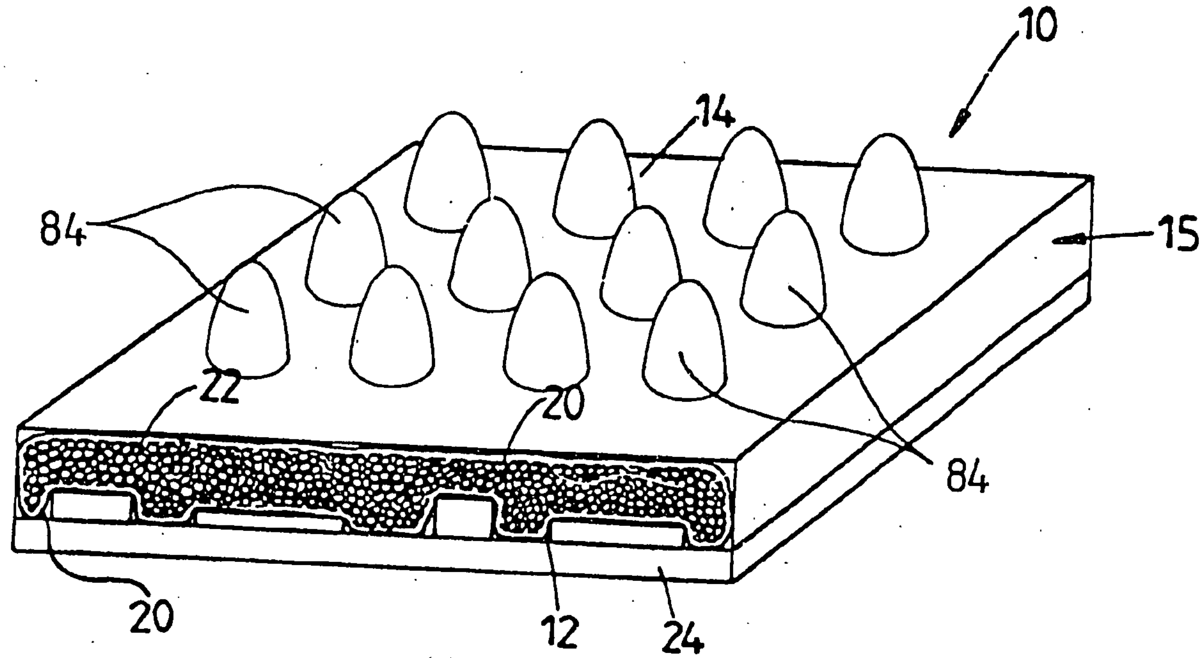


FIG 14